

Investigating Digital Collaboration: Human Factors in Artificial Intelligence-Driven Collaboration Platforms for Resilient Port

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ABSTRACT

The adoption of digital technology in maritime transport is currently essential and inevitable. Major global ports embracing these advancements to improve efficiency and resilience. However, the next frontier involves fostering digital collaboration among stakeholders in the maritime transport ecosystem. As Artificial Intelligence (AI) becomes critical in enhancing productivity, its integration into digital technologies is key to creating resilient ports capable of mitigating disruptions. While technological aspects have received ample attention, there is a lack of research addressing the human factors involved in AI driven digital collaboration platforms—particularly in Indonesian ports, which face unique geographical and disaster-related challenges due to the nation's archipelagic nature. This study explores the human factors influencing the successful implementation of digital collaboration in Indonesian ports. It identifies human factor barriers that hinder the effective use of AI-driven technologies. Using qualitative interviews and simple quantitative survey, this research investigates the strategies necessary to address these human-centric challenges and optimize the role of individuals in digital transformation. Qualitative data is analyzed using thematic analysis, while quantitative data is presented using the Importance-Performance Matrix and Adoption Matrix. The findings present actionable strategies to overcome human factor barriers. A regulatory framework is proposed aimed at enhancing the resilience of Indonesia's port system. This paper offers a practical, human-centered approach to digital collaboration, ensuring that Indonesia's port ecosystem becomes more adaptable to future disruptions and sustainable in a rapidly evolving digital landscape.

Keywords: artificial intelligence, digital collaboration, human factors, Indonesia, port resilience

1. INTRODUCTION

1.1 Research Background

The adoption of digital technology in seaports and maritime transport has become inevitable due to the increasing demands for efficiency, productivity, and sustainability in global trade. Major ports around the world are continuously integrating advanced technologies such as automation, Internet of Things (IoT), blockchain, and Artificial Intelligence to streamline operations and enhance decision-making (Notteboom *et al.*, 2022). These digital transformations have significantly improved port operations, from cargo handling to real-time tracking and data sharing, making maritime logistics more efficient and responsive to the needs of the global supply chain.

Moreover, as maritime transport plays a critical role in global trade, port resilience is essential for withstanding and adapting to disruptions, such as natural disasters, economic crises, and supply chain bottlenecks. Ports must be able to continue functioning effectively under adverse conditions to prevent major disruptions in the supply chain (UNCTAD, 2024). Economic consequences of port disruptions could approximately reach \$ 63.1 billion in trade at risk annually when there are inadequate resilience measures (Rose & Wei, 2013; Verschuur *et al.*, 2022). Post COVID-19 pandemic the importance of operational flexibility and adaptability in port management is highlighted. The pandemic forced ports to implement rapid changes in their operational practices, making the development of port resilience a key priority and digital technology offers crucial tools for achieving this (Fedi *et al.*, 2022; Notteboom *et al.*, 2021).

Nonetheless, the next step beyond the adoption of digital technology is fostering digital collaboration among the various players involved in port and maritime logistics. Digital collaboration, which involves seamless communication, information sharing, and coordination between stakeholders, business entities, and operational players, is necessary to maximize the benefits of digital

technology. The integration of advanced digital technologies, such as AI, the Internet of Things (IoT), big data analytics, and automation, facilitates improved communication and coordination among stakeholders, thereby optimizing port operations and supply chains (Almeida, 2023; Gerrero-Molina, 2024; Yau *et al.*, 2020). As ports evolve into smart ports, they leverage these technologies to create interconnected systems that enhance decision-making and operational performance (Gerrero-Molina, 2024; Min, 2022).

The use of Artificial Intelligence (AI) in maritime transport systems is rapidly expanding, offering opportunities to enhance efficiency and decision-making (Munim *et al.*, 2020; Abdelsalam & Elnabawi, 2024). IoT, Big Data, and AI technologies, along with their predictive abilities, have contributed in various ways to enhancing supply chain efficiency (Notteboom *et al.*, 2022). The prominence of AI has been increasing in recent years, including its usage in digitalization of maritime transportation. The adoption of AI may facilitate the

reallocation of human resources to more complex tasks that remain beyond the current AI systems capability. Moreover, AI-enabled digital collaboration will greatly enhance the effectiveness and impact of efforts to strengthen port resilience.

AI can be categorized into several types, primarily including narrow AI, which is designed for specific tasks, and general AI, which exhibits intelligent behavior across a wide range of activities, similar to human cognitive abilities. In the context of industrial evolution, Industry 3.0 is characterized by digitalization and automation of production processes, relying mostly on computer systems and data computing. In contrast, Industry 4.0 emphasizes the integration of big data, advanced analytics, and AI technologies to create smarter, interconnected systems that enhance decision-making, efficiency, and flexibility in production and logistics.

Previous research that are relevant with this study, discussing port resilience and AI are described in Table 1 as follows.

Table 1 Previous related studies and novelty of this research.

Previous Research	Research Scope	Research Location	Aspects or Variables as Main Concern
Dui <i>et al.</i> (2021)	Predictive modeling and scenario-based assessments help ports identify vulnerabilities and mitigate risks.	Global ports and international trade routes	Risk mitigation, predictive modeling, port resilience
Dhanak <i>et al.</i> (2021)	Resilience assessment tools assist in prioritizing infrastructure investments and operational improvements.	Six ports in the Southeast United States	Infrastructure investments, resilience assessment, operational improvements
Boyke <i>et al.</i> (2022)	AI-driven decision support systems enhance crisis management and service continuity in ports.	Seismic design of port facilities in Indonesia	Crisis management, AI-driven support, service continuity
Ghazaleh (2023)	Explore the AI Business Drivers of Smart Port Digitalization and findings shows AI adoption in ports enhances operational efficiency through historical data analysis.	Employees of 12 terminals listed in the Gulf region (UAE)	AI adoption, operational efficiency, historical data utilization
Wahyuni <i>et al.</i> (2020)	Port competitiveness model for Indonesia highlights the role of technology in improving business performance.	Ports in Indonesia	Port competitiveness, business performance, technological adoption
This research	Explore Human Factors in Artificial Intelligence-Driven Digital Collaboration Platforms for Resilient Port	In Indonesian Ports Pelindo	Human Factor barriers and enablers

This study differs from previous research because it focuses on human factors in order to reach resilience. However, the human aspect remains crucial, as the boundaries between tasks managed by AI and those requiring human intervention must be clearly defined. Strengthening human capital capacity to effectively use AI is essential for maximizing its benefits. Literature on digital transformation in ports is expanding (Beresford *et al.*, 2004; Heilig *et al.*, 2017), still, there remains a significant gap in understanding the human factors affecting the adoption of digital tools in ports.

Existing research mentioned the existence of human factors in the adoption of port digital platforms, such as in blockchain and augmented reality, however, they have not explored in depth what these human factors are (Pu & Lam, 2021; Brunila *et al.*, 2021; Oever *et al.*, 2023; Yang & Hsieh, 2024). In particular, studies on port resilience have often mentioned human factors such as stakeholder engagement and effective communication (Mansouri *et al.*, 2010; Becker

& Caldwell, 2015; Wei *et al.*, 2020), however, they have not thoroughly examined details each human factor. Identifying and addressing human factor barriers to implementing digital collaboration platforms is vital to optimizing maritime logistics operations. By overcoming these barriers, the industry can build a more resilient and adaptive ecosystem, capable of handling future disruptions.

Digital collaboration tools to enhance resilience in supply chain is critical since customer demand for product variety, particularly for short life-cycle items like food, apparel, toys, and computers, needs to be aligned with the supply provided by manufacturers and retailers (Simatupang & Sridharan, 2002). Through enhanced collaboration, ports can build stronger networks, share critical data, and improve the overall resilience of the entire supply chain. Additionally, there is limited research on practical, human-centered strategies to address these barriers within the unique geographical and disaster-prone context in Indonesian. A study in the context of Indonesian ports shows that digital

adoption and service quality do not have positive impact on port business sustainability (Utama *et al.*, 2023). However, latest research in Indonesian ports by Lasse, *et al.* (2024) investigates that relationship between digital collaboration and port resilience exist. It examines whether port integration and human factors represented by transformational leadership act as mediators or moderators in building resilience, using qualitative interviews with diverse stakeholders. The findings suggest that digital collaboration plays a key role in enhancing port resilience, and a theoretical framework is proposed for future testing (Lasse, *et al.*, 2024).

Research on ports in Indonesia presents unique characteristics that differentiate it from similar studies in other archipelagic nations. One of the primary distinctions lies in the specific challenges and opportunities that Indonesian ports face due to the country's geographical configuration and socio-economic context. Indonesia, as an archipelagic state comprising over 17,000 islands, necessitates a distinct approach to port development and maritime logistics compared to other countries with fewer islands or different geographical layouts. Research on Indonesian ports is unique due to the country's archipelagic nature, requiring distinct maritime logistics and port development strategies. Compared to other archipelago countries, key challenges include integrating peripheral ports into global markets despite limited infrastructure (Wiradanti *et al.*, 2020), while government policies and economic reforms play a crucial role in enhancing port competitiveness (Wahyuni *et al.*, 2020; Iman *et al.*, 2022). Additionally, inclusive growth and stakeholder engagement are emphasized in port development, distinguishing Indonesia from other archipelagic nations (Jansen *et al.*, 2018). So far none other research has been conducted on the use of AI in ports specifically at archipelagic countries.

1.2 Indonesian Ports Pelindo: Current and Future Plans in Digital Collaborations for Resilient Maritime Transport Ecosystem

PT Pelabuhan Indonesia (abbreviated as Pelindo) is Indonesia's largest port operator. Pelindo face significant logistical challenges due to the country's vast archipelagic geography, which spans thousands of islands. To address these complexities, Pelindo has actively develop standardized operations across its ports and embraced digital technologies to enhance efficiency in operations, including cargo handling and logistics management (Pelindo, 2024). Additionally, Pelindo collaborates with global terminal operators to improve service quality and expand its operational capabilities (Pelindo, 2024). As the main state-owned enterprise responsible for port services, Pelindo plays a critical role in shaping the nation's maritime infrastructure, adhering to government regulations and policies while ensuring that Indonesia's ports remain competitive and resilient in the face of growing global trade demands. The following Figure 1 describes Indonesia's large archipelago compared to the Europe Continent.

Pelindo is Indonesia's largest port operator, providing a wide range of services including container and non-container handling, marine and port equipment services, logistics, and hinterland development. As a state-owned enterprise, Pelindo plays a critical role in managing the country's extensive port infrastructure, overseeing hundreds of ports across Indonesia. Given the nation's complex

archipelagic geography, which consists of over 17,000 islands, Pelindo's operations are vital in ensuring seamless maritime logistics and connectivity. Despite the challenges posed by Indonesia's geographical conditions, Pelindo has been instrumental in modernizing port operations, enabling efficient cargo movement across the islands.

In terms of regulatory context, Pelindo is the largest state-owned port operator in Indonesia, separate from port authorities and regulators, which oversee compliance and safety standards (Pelindo, 2024). Since 2010, Pelindo has made significant strides in adopting digital technology, standardizing systems and operations across its numerous ports to improve efficiency. This digital transformation has enhanced Pelindo's ability to handle increasing maritime traffic and has supported partnerships with global terminal operators such as Hutchinson Ports, Mitsui, PSA, NYK, and DP World through its subsidiaries. It not only strengthened operational capabilities and introduced best practices in port management, but also becomes foundation for expansion of maritime and trade networks. Furthermore, digital collaboration has been integrated into various business lines within the Pelindo Group, reinforcing the company's commitment to innovation and global standards in maritime operations.

Pelindo envisions a future where digital collaboration transforms Indonesia's maritime transport ecosystem into a resilient and efficient network. As the nation's largest port operator, Pelindo aims to integrate cutting-edge digital technologies across its business segments, including container and non-container handling, marine services, logistics, and hinterland development. Recognizing the challenges posed by Indonesia's vast archipelagic geography, Pelindo is committed to bridging logistical gaps through innovation and advanced data-driven solutions.

The company plans to expand its digital collaboration platforms to foster seamless interactions between ports, stakeholders, and regulators. This includes the implementation of integrated systems powered by Artificial Intelligence (AI), big data analytics, and blockchain to ensure real-time visibility, traceability, and enhanced decision-making across its port operations which is still on progress. Pelindo's focus on automation and interoperability aims to standardize processes throughout its network of over 100 ports, allowing for streamlined cargo movement and optimized resource allocation. Partnerships with more global terminal operators and technology providers remain central to Pelindo's strategy. Moving forward, Pelindo seeks to leverage further partnerships to adopt global standards and expand its digital footprint.

Regarding the use of AI in digital collaboration platforms, Pelindo is in the initiation and development phase of leveraging AI across various applications. One notable example is the AI-driven port equipment maintenance system, which allows for predictive maintenance by analyzing equipment performance data to anticipate failures before they occur. Additionally, Pelindo employs AI for risk management within its port ecosystem, enabling better assessment and management of potential risks. The finance shared service center at Pelindo utilizes AI to streamline operations and enhance financial decision-making processes. Furthermore, the company is developing an early-stage search engine that enables big data analytics for internal use,

improving data accessibility and insights. Lastly, Pelindo is integrating AI with the Internet of Things (IoT) in its advanced terminal at Teluk Lamong (Rahman, 2021), facilitating automated port operations and optimizing efficiency in cargo handling and logistics. These AI initiatives showcase Pelindo's commitment to modernizing its operations and improving service delivery within the logistics sector.

Digital collaboration to achieve port resilience will be more effective and have a significant impact if enabled by AI. This is what drives Pelindo to simultaneously develop digitalization and the implementation of AI, even though AI is still in the initial phase (Pelindo, 2025). Moreover, Pelindo is investing in workforce digital literacy and advanced training programs to ensure its human capital adapts to the evolving technological landscape. Initiatives like e-learning platforms and simulator-based training for operational staff will be rolled out to improve efficiency and minimize resistance to change. By combining advanced digital tools, strategic partnerships, and an emphasis on workforce development, Pelindo aspires to position itself as a global leader in resilient maritime transport, ensuring sustainable and equitable connectivity across Indonesia's islands and beyond.

1.3 Research Objectives and Research Questions

This study examines key human factors that impact the successful adoption of digital collaboration in Pelindo, identifying key barriers that obstruct the effective utilization of AI-driven technologies. The main three research questions are as follows. 1) Are digital collaborations platforms used in ports and does it lead to port resilience?; 2) Does the digital collaboration platform used in Indonesian Ports able to support collaboration between internal and external parties and has AI features?; 3) What are key human factors as barriers that affect the adoption of digital collaboration platforms in Indonesian Ports and what are the solution to improve port resilience? Through qualitative interviews, the research investigates strategies to overcome these human-centered barriers or challenges and improve the role of individuals in the digital transformation process, participate in digital collaboration platforms, enhance operational efficiency and decision making, which ultimately establish resilience for the maritime transport ecosystem. This research also proposes human centered strategy for practitioners and regulators.

2. LITERATURE REVIEW

2.1 Digital Collaboration in Port and Maritime Transport

The COVID-19 pandemic has significantly accelerated the use of digital collaboration tools in the port sector, prompting many organizations to implement new digital workflows to adapt to evolving challenges (Bešković *et al.*, 2022; Bocayuva, 2021). This shift has underscored the critical role of digital platforms like Port Community Systems (PCS), which act as collaborative hubs for stakeholders such as port authorities, shipping companies, and logistics providers (Simoni *et al.*, 2020; Tijan *et al.*, 2021). These platforms not only streamline operations but also improve data sharing and transparency, essential for effective decision-making and managing crises (Ferreira, 2024; Jiang *et al.*, 2021). The adoption of digital twins in port operations marks a further

leap in collaboration, allowing real-time monitoring and simulation of port activities for stakeholders to collaboratively analyze and optimize processes (Cumo, 2021; Eom, 2023; Klar *et al.*, 2023). This technology encourages a proactive approach to port management, enabling early identification and resolution of potential issues, thereby boosting operational resilience (Ren, 2024; Yu *et al.*, 2023).



Figure 1 Indonesia's archipelago in contrary to Europe continent.

Additionally, workforce training and capacity building are vital for ensuring successful digital collaboration in ports. As new technologies are implemented, it is crucial to equip employees with the necessary skills to effectively use these tools (Cumo, 2021; Ferreira, 2024). Collaborative training programs can help address knowledge gaps and foster an innovative culture within port communities (Haasis & Hapsatou, 2022; Ortiz-Rey *et al.*, 2020).

2.2 Establishment of Resilience in Ports and Maritime Transport Ecosystem as Common Goal

Integrating advanced technologies and data analytics into port operations is crucial for enhancing resilience. Predictive modeling and scenario-based assessments enable port managers to identify vulnerabilities and develop targeted risk mitigation strategies (Dui *et al.*, 2021). For instance, resilience assessment tools provide valuable insights into the potential effects of various disruptions, helping ports prioritize infrastructure investments and operational improvements (Dhanak *et al.*, 2021). As global trade expands and disruptive events become more frequent, building resilience is essential for ports' long-term success. This requires adopting adaptive practices, engaging stakeholders, and leveraging technology to create a more resilient port ecosystem.

The ability to effectively manage crises, such as natural disasters or operational disruptions, is essential to port resilience. By incorporating AI-driven decision support systems into comprehensive crisis management plans, ports can improve their responsiveness during emergencies (Boyke *et al.*, 2022). This proactive strategy reduces downtime and ensures service continuity. A robust regulatory framework is critical for the efficient functioning of ports. The Indonesian government has introduced policies to improve port governance and streamline operations such as the merger of previously 4 state-owned port operators,

port standardization and digitalization in the maritime transport sector (Utama *et al.*, 2023; Lasse, *et al.*, 2024). However, bureaucratic inefficiencies can undermine these regulations such as poor implementation of port security policy and competing interests between relevant actors, causing delays and higher operational costs (Samy, 2023). Simplifying regulations and improving inter-agency coordination can strengthen port resilience.

2.3 Artificial Intelligence Tools for Digital Collaboration and Port Resilience

The port industry represents a natural fit to leverage AI due to certain characteristics that align well with AI strengths, such as intricate operational processes and substantial reliance on human. Those business drivers drove the adoption of AI tools to enhance operations by utilizing historical port data to expedite various processes (Ghazaleh, 2023). Wahyuni *et al.* (2020) explored and formulated a port competitiveness model specifically for Indonesian ports, which includes elements such as government support, operational performance, and business support. The study examined factors influencing port effectiveness and highlighted the lag in Indonesia’s adoption of contemporary technology. Utilization of contemporary technology such as AI-assisted analytics can be leveraged to improve port competitiveness through improved business performance and revenue in the port community. Additionally, empowering AI augmented platform may yield seamless communications between port operator, shipping lines, port authority, and agents (Huang *et al.*, 2018). There is a strong linkage between digital transformation of a port and its performance (Dalaklis *et al.*, 2022). The Port of Gothenburg has launched a digital platform that connects important stakeholders in port area, namely the shipping companies, freight forwarder, and rail operators. There were a plenty of initiatives to support the launch of the digital platform, including retraining the workers and cultural adaptation.

2.4 Human Factors in Digital Technology Adoption and Collaboration

The adoption of digital technology and the success of digital collaboration are significantly influenced by human factors, as highlighted in various studies from the literature. These factors play a critical role in determining whether organizations can effectively implement and sustain digital initiatives. These barriers consist of the lack of digital literacy and skills, cultural resistance to change, interoperability issues, data privacy and security concerns, resource constraints and regulatory or bureaucratic challenges, in which they hinder the adoption process of digital collaboration. Meanwhile enablers identified are comprehensive trainings, change management, investment in user-centric design and interoperable system, robust data governance frameworks, leveraging collaborative partnerships and leveraging AI for decision support, could drive successful outcomes. The following Table 2 and Table 3 summarize the key human factor barriers and enablers identified from the literature, along with supporting sources that provide evidence and insights into these dynamics. Overall, these factors are obtained from literature or research conducted not older than 2015, which shows that digital adoption or digital collaboration are more dominantly discussed in the 21st century. When these factors are clustered further into categories of internal and external, it could be seen that more human factors are actually issues in the internal of the organization or company itself.

The literature review in this research was conducted using common search engines and academic databases, utilizing relevant keywords such as “Port resilience”, “Indonesian ports”, “artificial intelligence” and “human factors”. These keywords were strategically chosen to identify peer-reviewed journal articles, industry reports, and policy documents that provide comprehensive insights into the unique challenges and developments in Indonesia’s port sector.

Table 2 Human factors as barriers in digital collaboration for port resilience.

Aspects	References	Category
1. Digital Literacy & Skills Gap	Al-Matari <i>et al.</i> (2022); Uzule & Budanceva (2023); Khodaria <i>et al.</i> (2019)	Internal
2. Cultural Resistance to Change	Hu <i>et al.</i> (2020); Helgesen & Ramsdal (2022); Solem <i>et al.</i> (2021); Legowo & Sorongan (2022); Brunila <i>et al.</i> (2021)	Internal
3. Interoperability Issues	Hannon (2024); Hu <i>et al.</i> (2022); Tikkanen (2024); Castillo-Carandang <i>et al.</i> , (2020); Sari (2023); (Yin, 2022); Heilig <i>et al.</i> , (2017)	Internal
4. Data Privacy and Security Concerns	Barbera <i>et al.</i> (2020); Solem <i>et al.</i> (2021); Zhang (2023); Faro <i>et al.</i> (2021)	External
5. Resource Constraints	Sawale (2023); Imran <i>et al.</i> (2021); Malchenko & Smirnova (2019); Yin & Ran (2022)	Internal
6. Regulatory and Bureaucratic Challenges	Almeida (2023); Faro (2024)	External

3. METHODOLOGY

This study employs a qualitative approach, focusing on in-depth interviews to gather insights from key stakeholders in Indonesian ports. Given the geographical challenges of Indonesia’s vast archipelago, the interview process was conducted both on-site and through video conferencing platform. This method allowed for greater flexibility in

reaching respondents across various islands. The combination of face-to-face and virtual interviews ensured a comprehensive understanding of the human factors influencing digital collaboration, despite the logistical difficulties of the region. Interviews in supply chain management and transportation studies are critical because it offers a deeper understanding and stronger explanation of the phenomena being studied (Golicic & Davis, 2012). This

research is one part of a larger ongoing PhD project. The primary goal of the PhD research is to explore and validate

the connection between digital collaboration and the resilience of ports.

Table 3 Enablers for human factors issues in digital collaboration for port resilience.

Aspects	References	Category
1. Comprehensive Training Programs	Farzadmehr (2023); Human <i>et al.</i> (2022); Zhang (2023); Baig (2023); Chan (2023)	Internal
2. Change Management Strategies	Wu (2024); Tóth (2023); Liu <i>et al.</i> (2019); Fehily <i>et al.</i> (2015); Kartikawati (2024);	Internal
3. Investment in User-Centric Design	Steffen <i>et al.</i> (2022).	Internal
4. Investment in interoperable system	Crabtree <i>et al.</i> (2022); Raisch & Krakowski (2021); Trstenjak (2023); Firmansyah (2024)	Internal
5. Robust Data Governance Frameworks	Verschuur <i>et al.</i> (2022); Dutta (2019); Zeiringer & Thalmann (2021); Yesilyurt <i>et al.</i> (2022); Yuan <i>et al.</i> (2023)	External
6. Leveraging Collaborative Partnerships	Arrigoni <i>et al.</i> (2019); Duarte <i>et al.</i> (2022); Wise & Kostelecky (2018); Eri <i>et al.</i> (2021)	External
7. Leveraging AI (and Advanced Technologies) for Decision Support	Mileski <i>et al.</i> (2018); Dui <i>et al.</i> (2021); Hu <i>et al.</i> (2022)	Internal

An Interview Protocol is prepared before interviews were conducted. To ensure ethical considerations were met, all respondents were asked for their informed consent prior to participation. Each respondent was provided with a clear explanation of the research objectives, an example of a digital collaboration platform and the relevance of the study to their work in the maritime transport sector. The interview focused on five main questions, designed to explore the respondents' perceptions and experiences with digital collaboration. The questions addressed the current state of digital platforms at their workplaces, the role of digital collaboration in enhancing resilience and whether it has Artificial Intelligence in the system, key human factor barriers to adoption, enablers or strategies to overcome those barriers, and suggestions for future research on the topic. The interview protocol is detailed in the Appendix.

The study included 20 respondents, each interviewed for approximately one hour. The respondents held influential positions within the maritime industry, including Directors in Subholding Companies, Directors in Subsidiary Companies, Executive Directors of Regional representative offices, General Managers of ports representing the major islands of Indonesia, and Group Heads in Headquarters Office. Their varied backgrounds provided a diverse set of perspectives on the challenges and opportunities of digital collaboration in the Indonesian port system.

Thematic coding and analysis approach was used to analyze the data collected from the interviews. This method allowed for the identification of key themes and patterns related to human factors in digital collaboration. The analysis revealed not only common barriers mentioned in the literature, such as resistance to change and skill gaps, but also additional context-specific challenges unique to the Indonesian port environment. Furthermore, the findings highlight practical enablers for improving human factors in digital collaboration, providing a foundation for the development of more resilient and adaptive port systems.

Lastly, a simple survey with quantitative measurement were asked to respondents. They were asked to answer in a Likert scale of 1 to 7 of how their organization/company perceive to these statements: 1) Digital collaboration platforms are important to improve port resilience; 2) Digital

collaboration platforms we have currently has contributed to improve port resilience; 3) We are confidence to learn more about AI and digital collaboration platforms. Afterwards, those quantitative data was analyzed using the Importance-Performance Matrix (IPM) and the Adoption Matrix as analytical frameworks to measure and interpret quantitative data collected from respondents. These tools, rooted in established literature, provide structured methods for evaluating priorities and adoption rates of initiatives or innovations.

Despite emerging approaches are trending applied in maritime transport research nowadays, still interviews, questionnaires and case studies are still commonly used and becoming classical approach to collect data which draws meaningful inferences (Yan *et al.*, 2021). Furthermore, research findings are plotted in The Importance-Performance Matrix and The Adoption Matrix. Previous related research described in Table 1 has not used this particular approach using Importance-Performance Matrix and Adoption Matrix. Hence, this approach contributes another unique view in research on AI in maritime transport.

The Importance-Performance Matrix (IPM) is widely attributed to Martilla and James (1977 in Slack, 1994) as seen in Figure 2, introduced in their seminal article in the Journal of Marketing. The framework helps organizations prioritize areas of improvement by mapping attributes based on their importance to stakeholders and their perceived performance. Attributes deemed highly important but underperforming signal critical areas requiring immediate attention, while those with high performance and importance represent strengths to maintain. The IPM has been utilized extensively across disciplines such as service quality assessment, strategic management, and policy evaluation, as seen in studies analyzing healthcare services, tourism management, and customer satisfaction (Azzopardi & Nash, 2013; Abalo *et al.*, 2007).

The Adoption Matrix as seen in Figure 3, popularized by Harvard Business Review (2024), is designed to categorize innovations or processes based on their adoption stage and perceived value. It helps identify barriers to adoption and guides strategies for scaling innovations. This matrix has been applied in various fields, including

technology implementation, educational reform, and public policy. For instance, Moore and Benbasat (1991) utilized a similar framework to examine factors influencing technology acceptance in organizations.

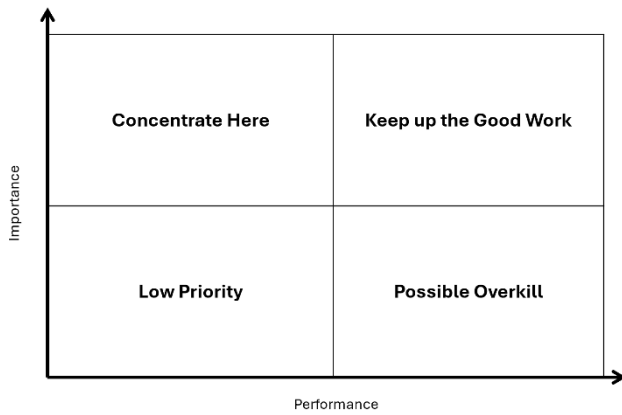


Figure 2 Importance-performance matrix.

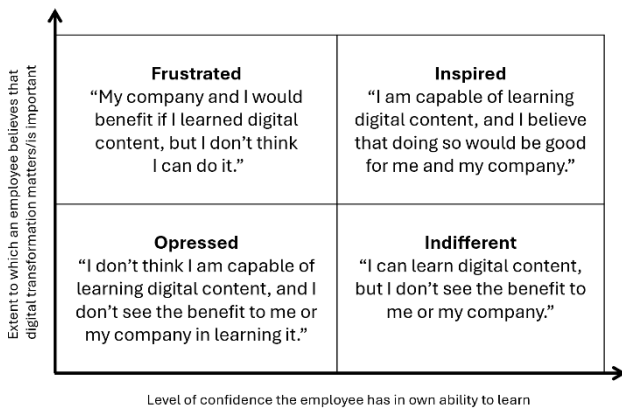


Figure 3 Adoption matrix.

By integrating these frameworks, the study provides a dual perspective: IPM highlights performance gaps critical for strategic intervention, while the Adoption Matrix contextualizes the maturity and readiness of digital collaboration initiatives. Together, these tools offer a robust approach to assess the efficacy and adoption dynamics of innovative practices in maritime operations, bridging theoretical insights and practical applications.

4. FINDINGS

4.1 Human Factors Barriers

Drawing insights from interviews, six key themes emerged as barriers: cultural resistance to change, low digital readiness, concerns about data sharing, interoperability challenges, resource constraints, and governance gaps. Cultural resistance was identified as a major barrier. Many port workers fear job displacement due to digital technologies, compounded by Indonesia's demographic pressures to create and sustain employment for future generations. Resistance to change is also deeply cultural, with a strong tendency to adhere to traditional practices and avoid unfamiliar methods. Addressing these fears requires re-skilling initiatives to transition surplus labor into back-office or other supportive roles, demonstrating how technology can complement rather than replace jobs.

Another significant issue is low digital readiness among port employees, particularly in smaller feeder ports. This gap is largely due to disparities in education levels between workers in urban and rural areas. Basic-level training on port operations, planning, and control is essential and must be implemented nationwide using replicable methods like "training for trainers." Enhancing foundational digital literacy would build confidence and prepare the workforce for adopting more advanced technologies.

Concerns over data sharing also hinder collaboration. Many respondents expressed fears about data misuse by unauthorized entities, such as competitors or intermediaries like freight forwarders. These fears are exacerbated by Indonesia's relatively weak cybersecurity infrastructure compared to regional neighbors. Strengthening digital security and establishing transparent data governance frameworks will be crucial to overcoming this barrier and fostering trust in collaborative platforms.

Interoperability issues further complicate digital transformation efforts. Within Pelindo's various business segments, disparities between systems create inefficiencies, especially in non-containerized and logistics services. While container handling systems are more mature and integrated, a lack of standardization elsewhere undermines collaboration. Unified digital platforms capable of integrating diverse systems are essential for overcoming these challenges.

Resource constraints, particularly financial, also pose a significant barrier. Digital collaboration platforms require substantial investments in infrastructure, regular training, and system updates. These investments are especially critical in smaller ports with gaps in basic infrastructure, such as reliable electricity. Measuring the return on investment, especially for training programs, adds to the complexity of adopting digital solutions on a wide scale.

Governance gaps and bureaucratic inconsistencies across regions also impede progress. Ports in rural areas often lack the governance maturity seen in major hubs, making it challenging to implement AI-driven platforms uniformly. Local political and regulatory factors often take precedence over data-driven decision-making, leading to a reliance on human intervention that varies from port to port.

These findings emphasize the importance of addressing human factors to enhance digital collaboration in Indonesia's port sector. Cultural resistance can be mitigated through inclusive training programs and clear communication about the benefits of digital technology. Digital literacy must be improved through scalable training initiatives, while robust cybersecurity measures and data governance frameworks are necessary to build trust. Interoperability issues demand a unified investment strategy for system integration, and governance alignment is essential for consistent adoption of AI-driven platforms. By addressing these challenges, Indonesia's port system can achieve greater resilience, efficiency, and global competitiveness.

4.2 Human Factors Enablers

Five key themes are identified as human factors enablers or solutions from interviews which are: structured training development, robust data governance, enhanced interoperability through partnerships, phased adoption of AI, and improved governance maturity. These solutions emphasize the importance of structured training programs,

robust data governance frameworks, improved interoperability through partnerships, phased implementation of AI, and enhanced governance maturity.

Structured training is pivotal in strengthening the digital foundation of Pelindo's workforce. Basic digital literacy training equips employees with the fundamental skills needed for digital collaboration, while advanced programs focusing on AI empower them to use technology for enhanced decision-making and operational efficiency. This approach must address the disparities in education and digital literacy between larger, advanced ports and smaller, rural ports. A "training for trainers" model is an effective strategy to disseminate knowledge throughout the network, ensuring scalability and uniformity. Advanced training not only improves individual capabilities but also fosters trust in technology across all levels of the organization.

Data governance frameworks emerged as critical for ensuring successful digital collaboration. Developing agreements among stakeholders about data disclosure, privacy, and cybersecurity ensures transparency while mitigating risks of misuse. Respondents stressed the need for clear protocols to guarantee that shared data benefits all parties, including freight forwarders, port operators, and regulators. Robust data governance fosters trust, which is essential for seamless collaboration.

Interoperability challenges within Pelindo's diverse operations can be addressed through strategic partnerships and investments. Collaborations with technology providers and global terminal operators offer best practices and innovations, enabling the integration of siloed systems. Improved stakeholder management practices are also necessary to harmonize expectations and processes across business segments. Such partnerships can facilitate seamless service delivery and enhance operational efficiency.

Leveraging AI within Indonesia's ports requires a phased approach. Respondents indicated that mature, urban ports should serve as pilot locations for high-level AI adoption. This gradual implementation allows smaller, rural ports to adapt over time, reducing resistance and disruption. Inclusivity and diversity must also be central to digital collaboration platforms. User-friendly designs and features that cater to various demographics, including individuals with disabilities, ensure broader acceptance and engagement.

The governance maturity across Indonesia's ports varies significantly, posing challenges to standardization. Strong regulations and consistent enforcement are needed to bridge these gaps. Respondents emphasized the importance of defining clear roles and relationships among regulators, operators, and private sector partners. Establishing incentives for compliance, such as cost reductions or faster service times, could motivate adherence to governance standards. Clear governance structures and aligned incentives enhance trust and collaboration among stakeholders.

These findings underscore the need for a multifaceted approach to implementing AI-driven digital collaboration platforms. Structured training programs lay a strong foundation for digital adoption, while robust data governance frameworks build trust. Partnerships and phased AI implementation facilitate scalability, and inclusive design ensures accessibility. Improved governance strengthens regulatory compliance and stakeholder cooperation. By

addressing these enablers, Pelindo is well-positioned to lead in digital innovation and strengthen Indonesia's maritime competitiveness on a global scale.

5. DISCUSSION

5.1 *Perceived Urgency to Establish Resilience*

Indonesia's archipelagic nature, with its reliance on maritime transport for economic stability, underscores the urgency of creating a resilient port ecosystem. Respondents highlighted that cultural resistance to change and governance gaps exacerbate vulnerability, particularly in rural and smaller ports. These gaps impede effective responses to disruptions, such as logistical inefficiencies or geopolitical tensions. The transition to AI-driven digital platforms is perceived not only as a technological necessity but as a means to ensure long-term resilience and competitiveness. By addressing these barriers—through structured training and fostering inclusivity—Pelindo can secure operational sustainability and adaptability.

5.2 *Strategy for the Establishment of Resilient Port and Maritime Transport Ecosystem*

Figure 4 and Figure 5 describes the research findings in Importance-Performance Matrix and Adoption Matrix. Findings shows that most of the respondents perceive their position to "Keep up the Good Work" and "Inspired". This implies that digital collaboration and the use of AI in order to develop port resilience needs to be continuously improved. Meanwhile outliers such as respondent who perceives that it is a "Possible Overkill" explains that if their current performance has been very good without the use of improvements in digital collaboration and AI, it implies that no further investment is needed to have an upgrade.

Developing resilience requires a holistic strategy that integrates human factors into technology adoption. Structured training emerges as a foundational step, empowering employees to adapt to digital tools while addressing education gaps between urban and rural ports. Respondents emphasized that phased AI implementation, starting with technologically mature locations, could serve as a blueprint for other ports. Interoperability is another critical element; partnerships with global operators and tech providers could streamline systems and reduce siloed operations. Data governance frameworks, underpinned by robust cybersecurity measures, further enhance resilience by fostering trust and enabling seamless collaboration across stakeholders.

5.3 *Confidence to Improve and Optimize AI-driven Digital Collaboration Platforms*

Despite challenges, there is optimism about leveraging AI to revolutionize port operations. Respondents expressed confidence that inclusive platform designs, accounting for diverse user demographics, could drive engagement. User-friendly interfaces and creative features make digital tools accessible even to employees with minimal digital literacy. Stakeholders recognize that AI-driven platforms have the potential to optimize decision-making, reduce inefficiencies, and adapt dynamically to disruptions. Building this confidence requires iterative feedback loops and showcasing pilot successes in major ports to demonstrate the tangible benefits of AI integration.

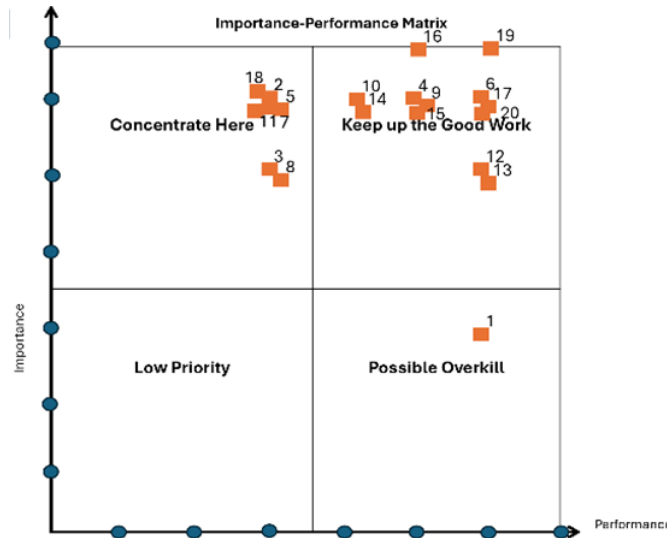


Figure 4 Research findings described in importance-performance matrix.

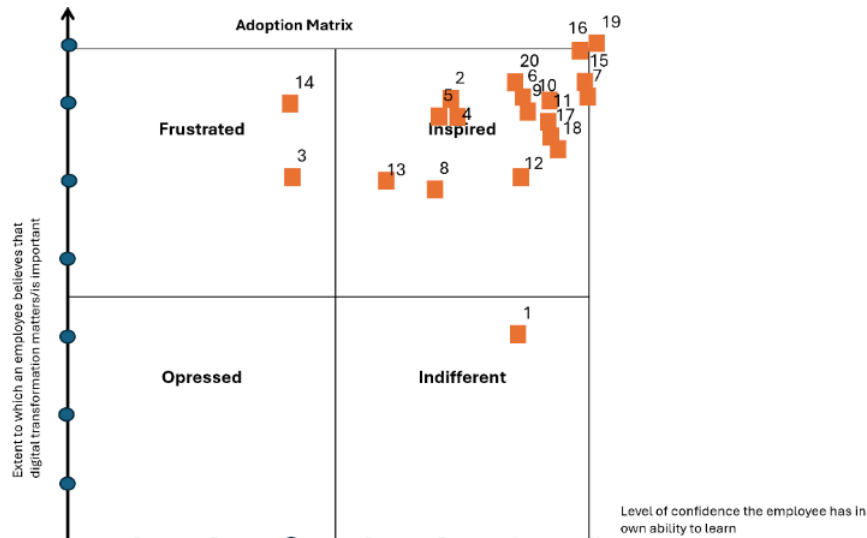


Figure 5 Research findings described in adoption matrix.

5.4 Strategy Proposed for Practitioners and Regulators

Practitioners and regulators play pivotal roles in enabling the transition to AI-driven digital collaboration. Practitioners should prioritize scalability by adopting the "training for trainers" model, ensuring knowledge is disseminated effectively across the network. Investments in digital infrastructure, particularly in rural areas, are crucial to bridging the technological divide. Practitioners should also promote inclusivity by designing systems that cater to diverse user needs, thereby fostering widespread adoption.

For regulators, establishing clear governance structures and incentives is essential. Strong regulations should standardize practices across ports while allowing flexibility for localized adaptations. Respondents suggested that incentives, such as cost reductions or expedited approvals, could encourage compliance with digital governance frameworks. Collaboration between regulators, operators, and private entities is necessary to align objectives and resources effectively. Finally, adopting international best practices in governance and cybersecurity can ensure Indonesia's port ecosystem remains globally competitive.

6. CONCLUSIONS

This study underscores the critical role of addressing human factors in implementing AI-driven digital collaboration platforms to build resilience within Indonesia's maritime transport ecosystem. The findings highlight a pressing urgency for transformation, given Indonesia's dependence on its extensive archipelagic network and maritime logistics for economic stability. Cultural resistance to change and governance gaps remain significant barriers, particularly in rural and smaller ports, where these issues exacerbate vulnerabilities and impede effective adaptation to disruptions. These challenges emphasize the need for a comprehensive approach that incorporates human-centric strategies alongside technological advancements.

Structured training emerges as a cornerstone for fostering digital readiness among port employees. Addressing disparities in education and digital literacy across regions, such programs can equip workers with foundational skills while empowering them to embrace AI for decision-making and operational efficiency. Initiatives like "training for trainers" can ensure knowledge dissemination across the vast network of ports, creating a

scalable model for widespread digital adoption. These efforts must be complemented by robust data governance frameworks, which are essential for building trust among stakeholders. Transparent protocols for data sharing and enhanced cybersecurity measures can alleviate fears of misuse, facilitating seamless collaboration within the ecosystem.

Phased implementation of AI technology is another crucial strategy, beginning with technologically mature ports that can serve as models for others. This staged approach reduces resistance and disruption, ensuring a smoother transition across the diverse operational landscape of Pelindo. Partnerships with global terminal operators and technology providers can also address interoperability issues, enabling the integration of siloed systems and enhancing operational efficiency. Moreover, inclusive platform designs that account for diverse demographics, including individuals with disabilities, can foster broader acceptance and engagement with digital tools.

Governance plays a pivotal role in ensuring uniformity and alignment across Indonesia's ports. Strong regulatory frameworks, coupled with consistent enforcement, can address regional disparities in governance maturity. Incentives for compliance, such as cost reductions or expedited services, can motivate adherence to governance standards. Clear roles and collaboration between regulators, operators, and private sector partners are necessary to streamline objectives and resource allocation effectively. Adoption of international best practices in governance and cybersecurity can further elevate Indonesia's maritime competitiveness on the global stage.

Optimism about leveraging AI-driven digital collaboration platforms to revolutionize port operations is evident among stakeholders. These platforms offer potential benefits, including optimized decision-making, reduced inefficiencies, and enhanced adaptability to disruptions. Iterative feedback loops and successful pilot programs in major ports can demonstrate the tangible benefits of AI integration, building confidence among users and stakeholders. The interconnectedness of human factors and technological readiness underscores the importance of a balanced approach to digital transformation.

In conclusion, AI-enabled digital collaboration is important for realizing port resilience, and human factors play a crucial role in its realization, within the context of Indonesian ports. Addressing cultural resistance, enhancing digital literacy, and fostering trust through robust governance and interoperability are essential steps toward establishing a resilient and inclusive port ecosystem. By aligning the efforts of practitioners and regulators, leveraging partnerships, and focusing on scalable and inclusive strategies, Pelindo is well-positioned to lead Indonesia's maritime sector into a future of innovation, sustainability, and global competitiveness. These advancements will not only strengthen the resilience of Indonesia's port ecosystem but also contribute to its broader economic growth and development.

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APPENDIX 1: INTERVIEW PROTOCOL

No	Interview Questions	Time Allocated for Discussion	Source from Literature
	Consent for participation in the research	5 minutes	-
	Explanation on research topic and example of a digital collaboration platform		
1.	What is your perception on digital collaborations and implementation as platform or application in your work place or port?	5 minutes	Dalaklis <i>et al.</i> (2022), Kusumawati (2023)
2.	Does the digital collaboration in your workplace or port aim to build resilience?	10 minutes	Ortiz-Rey <i>et al.</i> (2020), Eom (2023)
3.	Does the digital collaboration platform in your workplace, today or maybe in the future, able to support collaboration between internal and external parties? Does it have AI features?	10 minutes	Aslam (2023), Kusumawati (2023)

APPENDIX 1: INTERVIEW PROTOCOL (CONT'D)

No	Interview Questions	Time Allocated for Discussion	Source from Literature
4.	What are key human factors as barriers that affect the adoption of digital collaboration platforms in Indonesian Ports (Pelindo)?	10 minutes	Tijan <i>et al.</i> (2021), Mthembu & Chasomeris (2022)
5.	What needs to be done to solve those barriers and improve the human capital willingness and capability to adopt digital collaboration platforms to improve port resilience?	15 minutes	Carlan <i>et al.</i> (2016), Hyde <i>et al.</i> (2021)
6.	What suggestions do you have for future research?	5 minutes	Authors' follow up question

APPENDIX 2: SURVEY QUESTIONS

In a scale of 1 to 7, how do you or your organization/company perceive these statements?

No	Interview Questions	Source from Literature
1.	Digital collaboration platforms are important to improve port resilience.	Ortiz-Rey <i>et al.</i> (2020), Eom (2023), the adoption of Importance-Performance Matrix from Azzopardi & Nash (2013) and Abalo <i>et al.</i> (2007). The Adoption Matrix Harvard Business Review (2024)
2.	Digital collaboration platforms we have currently has contributed to improve port resilience.	
3.	We are confident to learn more about AI and digital collaboration platforms	

APPENDIX 3: SURVEY DATA

ID	Respondents' Background	Importance Score	Performance Score	Confidence to Learn Score	Position in IP Matrix	Position in Adoption Matrix	Human Factor Barriers	Enablers /Solution
1	Subholding for Container Handling Services	3	6	6	Possible overkill	Indifferent	<ul style="list-style-type: none"> Current platform has great performance Improving digital collaboration platform is unnecessary Cultural resistance to change 	<ul style="list-style-type: none"> Incentive & leadership support Change management Leveraging AI
2	Subholding for Non-Container Handling Services	6	3	5	Concentrate Here	Inspired	<ul style="list-style-type: none"> Digital literacy & skills gap Cultural resistance to change Interoperability issues 	<ul style="list-style-type: none"> Training Investment in interoperable system
3	Subholding for Logistics & Hinterland Devlp Services	5	3	3	Concentrate Here	Frustrated	<ul style="list-style-type: none"> Digital literacy & skills gap Cultural resistance to change 	<ul style="list-style-type: none"> Incentive & leadership support Training
4	Subholding for Marine & Equipment Services	6	5	5	Keep up the Good work	Inspired	<ul style="list-style-type: none"> Digital literacy & skills gap Cultural resistance to change Regulatory & bureaucratic challenges 	<ul style="list-style-type: none"> Incentive & leadership support Training Leveraging AI
5	Regional Office	6	3	5	Concentrate Here	Inspired	<ul style="list-style-type: none"> Digital literacy & skills gap Cultural resistance to change 	<ul style="list-style-type: none"> Training Investment in interoperable system
6	Regional Office	6	6	6	Keep up the Good work	Inspired	<ul style="list-style-type: none"> Data privacy and security concerns 	<ul style="list-style-type: none"> Robust data governance frameworks Leveraging AI Training

APPENDIX 3: SURVEY DATA (CONT'D)

ID	Respondents' Background	Importance Score	Performance Score	Confidence to Learn Score	Position in IP Matrix	Position in Adoption Matrix	Human Factor Barriers	Enablers /Solution
7	Regional Office	6	3	7	Concentrate Here	Inspired	<ul style="list-style-type: none"> Digital literacy & skills gap Cultural resistance to change 	<ul style="list-style-type: none"> Training Investment in interoperable system Leveraging collaborative partnership
8	Regional Office	5	3	5	Concentrate Here	Inspired	<ul style="list-style-type: none"> Digital literacy & skills gap Cultural resistance to change Interoperability issues Regulatory & bureaucratic challenges 	<ul style="list-style-type: none"> Training Investment in interoperable system Robust data governance frameworks Leveraging Collaborative Partnerships
9	Group Head in Headquarters	6	5	6	Keep up the Good work	Inspired	<ul style="list-style-type: none"> Interoperability issues Data Privacy and Security Concerns 	<ul style="list-style-type: none"> Robust data governance frameworks Leveraging AI
10	Group Head in Headquarters	6	4	6	Keep up the Good work	Inspired	<ul style="list-style-type: none"> Interoperability issues Data Privacy and Security Concerns 	<ul style="list-style-type: none"> Robust data governance frameworks Leveraging AI
11	Group Head in Headquarters	6	3	6	Concentrate here	Inspired	<ul style="list-style-type: none"> Digital literacy & skills gap Cultural resistance to change 	<ul style="list-style-type: none"> Change management Training Leveraging AI
12	Group Head in Headquarters	5	6	6	Keep up the Good work	Inspired	<ul style="list-style-type: none"> Digital literacy & skills gap Cultural resistance to change Resource constraints 	<ul style="list-style-type: none"> Training Leveraging AI Leveraging Collaborative partnerships Investment in interoperable system
13	Group Head in Headquarters	5	6	4	Keep up the Good work	Inspired	<ul style="list-style-type: none"> Digital literacy & skills gap Cultural resistance to change Regulatory & Bureaucratic challenges 	<ul style="list-style-type: none"> Incentive & leadership support Change management Training Leveraging Collaborative Partnerships
14	Group Head in Headquarters	6	4	3	Keep up the Good work	Frustrated	<ul style="list-style-type: none"> Digital literacy & skills gap Cultural resistance to change 	<ul style="list-style-type: none"> Training Change Management Incentives & leadership support Leveraging AI
15	Group Head in Headquarters	6	5	7	Keep up the Good work	Inspired	<ul style="list-style-type: none"> Interoperability issues Data Privacy and Security Concerns 	<ul style="list-style-type: none"> Robust data governance frameworks Investment in interoperable system Leveraging AI

APPENDIX 3: SURVEY DATA (CONT'D)

ID	Respondents' Background	Importance Score	Performance Score	Confidence to Learn Score	Position in IP Matrix	Position in Adoption Matrix	• Human Factor Barriers	• Enablers /Solution
16	Subsidiary company	7	5	7	Keep up the Good work	Inspired	<ul style="list-style-type: none"> • Interoperability issues • Data Privacy and Security Concerns 	<ul style="list-style-type: none"> • Robust data governance frameworks • Investment in interoperable system • Leveraging AI
17	Subsidiary company	6	6	6	Keep up the Good work	Inspired	<ul style="list-style-type: none"> • Current platform and digital collaboration has great performance 	Leveraging AI
18	Subsidiary company	6	3	5	Concentrate Here	Inspired	<ul style="list-style-type: none"> • Digital literacy & skills gap • Interoperability issues • Resource Constraints 	<ul style="list-style-type: none"> • Training • Investment in interoperable system
19	Subsidiary company	7	6	7	Keep up the Good work	Inspired	<ul style="list-style-type: none"> • Current platform and digital collaboration has great performance 	<ul style="list-style-type: none"> • Leveraging Collaborative Partnerships • Leveraging AI
20	Subsidiary company	6	6	6	Keep up the Good work	Inspired	<ul style="list-style-type: none"> • Current platform and digital collaboration has great performance 	<ul style="list-style-type: none"> • Leveraging Collaborative Partnerships • Leveraging AI